middle part of the roll. Continuous slow down to the end of the buffer tube will provide a monotonically reduced tension and a flattened EFL curve as shown in Figure 10 by arrow 113 which indicates flattening of the EFL curve.

It is anticipated that some deformations of thermoplastic materials are reversible (elastic) while the others are permanent (plastic). That is why the direct comparison of the EFL in the reeled material remaining on the spool to that unreeled is not always accurate. The EFL after reeling can be computed based on the value of EFL before reeling and plastic or residual strain, ε_θ^p, in the circumferential direction:

$$EFL_{Final} = EFL - \varepsilon_\theta^p. \quad (4.11)$$

The changes in microstructural properties and associated elongations leading to changes in EFL are summarized in Figure 11, which shows a relationship between tensile stress, shrinkage, time on reel and creep and how they may increase EFL of a buffer tube.

In the present invention, an expression for the decay parameter can be derived from Equation 4.10. As a practical approach, several cases with variable α should be considered to determine through iteration when the EFL is close to a desired constant level. The exact application of this formula would vary with relation to manufacturing facility and parameters, and should be optimized for each individual calculation to ensure that the desired level of EFL is maintained.

An example of this is demonstrated in Figure 12. In this Figure, a number of examples are shown, where the tension decay rate was varied for four typical cases of reel core stiffness. Odd numbered curves in Figure 12 correspond to circumferential stress. The goal was to obtain a constant-value distribution of circumferential stress. Curves 121, 123, 125, 127, 129 and 1211 show a sequence of the variable core stiffness, from "regular" rigid

(121 and 123) to soft core (125 and 127), then to a rigid core with a thin soft pad (curve 129) and finally, a core with increased stiffness (curve 1211). Numerical experiments revealed that the distribution of circumferential stress is very sensitive to the core stiffness and the decay rate in tension. The even number curves represent radial stresses as compared to roll radius.

Figure 13 presents a wider variety of computed cases with different relative core stiffness and decay rates of take-up tension. The numbers in the Figure represent minimum and maximum levels of circumferential stress. The shapes of the curves in Figure 13 show periodicity in the stress distribution and suggest how to control the stiffness of the core and take-up tension in order to achieve constant circumferential stress in the roll and subsequently, constant values of EFL. In particular, computations for $\alpha = 0.6$ and $\beta = -1.2$ produce a variation in the circumferential stress in the range from 92 to 96MPa; i.e. within ±2.5%.

Analysis of the distribution of circumferential stress suggests that there are three major zones. The first one is a zone of unstable solutions (or unstable behavior) in the stress distribution when the parameter β is positive. For different rates of decay in take-up load, the curves show a sharp transition to lower (compressive) stresses at the core surface. This may or may not be attributed to the properties of the logarithmic functions alone. The second zone corresponds to negative values of the parameter β, in the range from –1 to 0. In most cases, the region near the core surface exhibits a higher level of circumferential stresses. The curves for circumferential stress decay from the point on the reel core to the outer layer, often forming a minimum in the middle part of the roll. Variation between the maximum and minimum values in this zone is smaller than that in the first zone. Also, this variation seems

to be minimal for β close to -0.8 and small values of α (gray zone in the table). The third zone corresponds to a spool core with increased stiffness; i.e. $\beta = -2$. Several stress curve shapes are possible in this zone, generally with a small variation between the minimum and maximum values, with smaller variation more typical for a rapid decay in take-up tension.

Another validation analysis performed in the research and development of the present invention was a finite element analysis of a buffer tube wound on a reel. This was done because the stress distribution along the length of a buffer tube has an influence on the excess fiber length within the tube. A variation of stresses exists in the wound structure that results from the combined loading state of the applied longitudinal tension and radial compression due to the interaction of multiple layers. Several models were developed to simulate the process of winding a material under tension onto a reel. In each of the models, a wide sheet of material, with some given thickness, was used to approximate one full traverse of buffer tubes on a reel. This was done in order to reduce the problem to a two-dimensional, plane strain condition, since a full three-dimensional model of a long buffer tube would not be feasible. A plane strain analysis of the problem is reasonable because the most significant factor influencing the stress variation is the compression due to the multiple layers.

The first FEA model developed included a spiral-shaped sheet of material initially coiled around a reel in a stress free state. The outer diameter of the reel was 200.0 mm, and the thickness of the sheet was 3.0 mm. The structure consisted of ten layers L, with a gap of 0.5 mm between the layers to allow for tightening of the coil. The pre-coiled state helps to eliminate the numerical difficulties associated with dynamic winding of the material around a rotating reel. The finite element mesh for this model is shown in Figure 14A. The surface of the reel was created using a spiral so there would be a slight offset where the sheet is